(1) (a) Between node 1 and substrate:

\[ C = \frac{\varepsilon_0 \varepsilon_r (A)}{\varepsilon_0} \]

\[ \varepsilon_0 = 3.45 \times 10^{-11} \text{ F/m} \]
\[ \varepsilon_r = 1.5 \text{ } \mu\text{m} \]
\[ A = (14 \mu\text{m})(5 \mu\text{m}) = 70 \mu\text{m}^2 \]

\[ C = 1.11 \text{ fF} \]

(b) Since the substrate is grounded, it suffices to draw all caps between node 4 and the substrate (to get node 4 to ground):

\[ \text{Intermediate capacitance calculations:} \]
\[ C_{12} = \frac{C_{13}A_{13}}{\varepsilon_0} \left( \frac{1.45 \times 10^{-10} \text{ F/m}}{2.5 \mu\text{m}} \right) = 0.952 \text{ fF} \]
\[ C_{23} = \frac{C_{24}A_{24}}{\varepsilon_0} \left( \frac{1.45 \times 10^{-10} \text{ F/m}}{0.75 \mu\text{m}} \right) = 0.756 \text{ fF} \]
\[ C_{14} = \frac{C_{13}A_{13}}{\varepsilon_0} \left( \frac{1.45 \times 10^{-10} \text{ F/m}}{0.75 \mu\text{m}} \right) = 0.952 \text{ fF} \]
\[ C_{24} = \frac{C_{23}A_{23}}{\varepsilon_0} \left( \frac{1.45 \times 10^{-10} \text{ F/m}}{0.75 \mu\text{m}} \right) = 0.756 \text{ fF} \]
\[ C_{35} = \frac{C_{36}A_{36}}{\varepsilon_0} \left( \frac{1.45 \times 10^{-10} \text{ F/m}}{3 \mu\text{m}} \right) = 0.128 \text{ fF} \]
\[ C_{25} = \frac{C_{26}A_{26}}{\varepsilon_0} \left( \frac{1.45 \times 10^{-10} \text{ F/m}}{3 \mu\text{m}} \right) = 0.128 \text{ fF} \]
\[ C_{15} = \frac{C_{16}A_{16}}{\varepsilon_0} \left( \frac{1.45 \times 10^{-10} \text{ F/m}}{1.5 \mu\text{m}} \right) = 1.61 \text{ fF} \]

Between node 4 and node 1: 

\[ C_{10} + C_{21} = 0.736 \text{ fF} \]

(c) If nodes 2 and 3 are grounded, then there are no field lines that can interact between 1 and 4 through those nodes, and the circuit is as in (b), between 1 and 4 reduces to

\[ C_{10} + C_{21} = 0.736 \text{ fF} \]

(d) If nodes 2 and 3 are floating, then the circuit from (b) reduces to

\[ C_{10} \text{ in series with } C_{21} = \frac{C_{10}C_{21}}{C_{10} + C_{21}} = 0.184 \text{ fF} \]
\[ C_{31} \text{ in series with } C_{31} = \frac{C_{31}C_{31}}{C_{31} + C_{31}} = 0.184 \text{ fF} \]
\[ C_{10} + 1.035 \text{ fF} + 0.184 \text{ fF} + 0.184 \text{ fF} = 1.403 \text{ fF} \]
(c) "Active region" refers to the area on the right, as defined by the oxide mask.

Sheet resistance of n-type region: \( R_o = \frac{1}{\rho} \)

Here, \( \rho = 10^{-3} \) cm; From figure 2.8, this corresponds to \( \mu_a = 500 \text{ cm/}V\text{s} \) and \( t = 500 \text{ nm} \)

\[ R_o = \frac{1}{(1.6 \times 10^{-19})(10^4)(500)(0.5 \times 10^{-6})} = \frac{1}{416.7 \text{ k} \Omega} \]

To get an estimate of the resistance, we can count the number of squares and multiply by the sheet resistance.

From the drawing of the active region, we see that it takes up about 4.3 \((= 3 + 0.15 + 0.15)\) squares.

In this case, \( R = (4.3 \times (416.7 \text{ k} \Omega)) = 1.79 \text{ k} \Omega \)

(b) Depletion capacitance between n-type active region and p-type substrate:

\[ C_{de} = \frac{\varepsilon_s}{x_d} \]

where \( x_d \) = depletion width of this p junction

\[ C_{de} = \varepsilon_s \sqrt{\frac{\frac{1}{2e_s} \frac{1}{\varepsilon_s} \left( \frac{N_a}{N_d} \right)}{N_a + N_d}} = 5 \times 10^{-3} \text{ fF/}\mu \text{m}^2 \]

But the junction is reverse-biased at -2.5V.

\[ C_j = \frac{C_{de}}{1 - \frac{N_d}{N_a}} = \frac{C_{de}}{1 - 0.5} = 2.75 \times 10^{-3} \text{ fF/}\mu \text{m}^2 \]

Looking at the layout, we can count the number of \( \mu \text{m}^2 \) squares:

\[ \frac{5}{\mu \text{m}^2} \]

\[ C = 5 \times \frac{1.2 \times 10^8}{500 \text{ nm}} = 1.04 \text{ fF/}\mu \text{m}^2 \]

From the layout, we can see that there is 33 squares worth of poly on top of the 500 nm oxide layer, for an area of 33 \( \mu \text{m}^2 \)

\[ C = (0.063 \text{ fF/cm}^2)(33 \mu \text{m}^2) = 2.08 \text{ fF} \]

(d) The oxide layer between the metal and substrate has, on the average, a thickness of 1 \( \mu \text{m} \) (500 nm from oxide layer grown between substrate-poly, and another 500 nm from oxide on the same plane as that for poly)

\[ C \text{ (per unit area)} = \frac{5}{\mu \text{m}} \times 0.0345 \text{ fF/}\mu \text{m}^2 \]

Approximately 18 metal squares make up the top plate of the metal-substrate capacitor:

\[ C = (18 \mu \text{m}^2)(0.0345 \text{ fF/}\mu \text{m}^2) = 0.63 \text{ fF} \]

(e) Resistance of the polysilicon wire:

\[ R = 14 + 0.15 + 0.15 = 15.4 \mu \text{ohms} \]

\[ (80 \text{ ohm})(0.63 \text{ fF}) = 73 \text{ nF} \]
\[ V = \frac{933 \text{v}}{1.09 \text{kVA}} \]

\[ = \frac{2.39 \text{ff}}{(0.161 + 0.221 \text{ff})} \]

\[ = 8.27 \text{ff} \]

(3) \[ C_d = \frac{e_d}{x_d} \]

\[ \Rightarrow \quad C_d = \frac{e_d}{\sqrt{\frac{2}{e_d} \phi d \left( \frac{N_d N_D}{N_d + N_D} \right)}} \]

\[ = \frac{e_d}{\sqrt{2 e_d \phi d N_d}} \]

\[ \text{since} \quad N_d >> N_D \]

\[ \phi_d = V_T \ln \frac{N_d N_D}{N_d + N_D}, \quad \text{where} \quad V_T = 26 \text{mV}, \quad N_d = 1.5 \times 10^{19} \text{cm}^{-3} \]

\[ \Rightarrow \quad \phi_d = 0.7 \text{V} \]

\[ \Rightarrow \quad C_d = 6.3 \text{nF/cm}^2 \]

\[ C_d = \frac{C_d}{1 - \frac{N_d}{N_D}} \]

\[ \Rightarrow \quad V_B = -1: C = 4 \text{nF/cm}^2 \]

\[ -5: C = 6.3 \text{nF/cm}^2 \]

\[ -10: C = 1.6 \text{nF/cm}^2 \]

\[ C = (C_d)(A) \]

\[ \Rightarrow \quad V_B = -1: C = 4 \text{pF} \]

\[ -5: C = 2.2 \text{pF} \]

\[ -10: C = 1.6 \text{pF} \]

See attached plot for slope.

slope = \[ 3.65 \times 10^{-3} \text{ } \frac{1}{\text{pF}} \]